

PHOTOMASK

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Aerial Plane Inspection for Advanced Photomask Defect Detection

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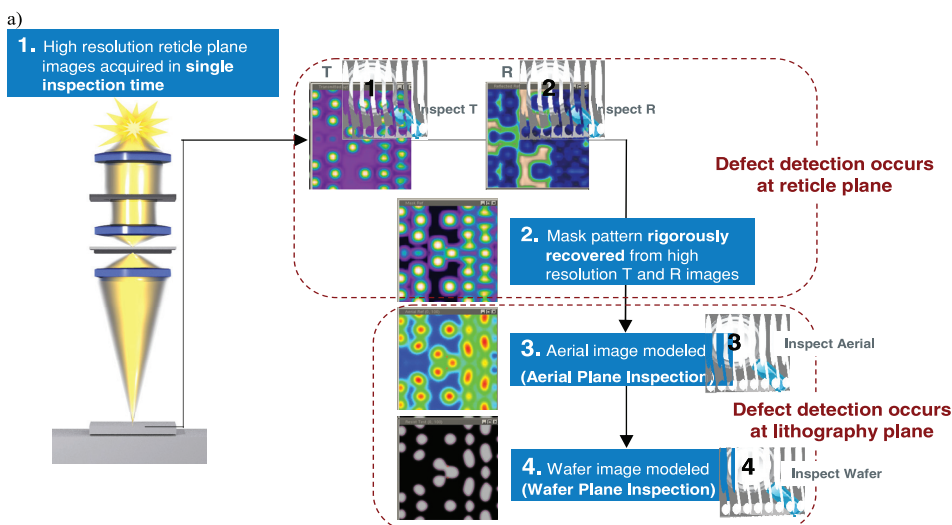
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ABSTRACT

A new methodology - Aerial Plane Inspection (API) - has been developed to inspect advanced photomasks used for the 45 nm node and beyond. Utilizing images from a high resolution mask inspection system, a mask image is recovered by combining the transmitted and reflected images. A software transformation is then performed to replicate the aerial image planes produced in a photolithography exposure system. These aerial images are used to compare adjacent die in a Die-Die inspection mode in order to find critical defects on the photomask. The mask recovery process and modeling of the aerial plane image allows flexibility to simulate a wide range of lithographic exposure systems, including immersion lithography. Any source shape, Sigma, and numerical aperture (NA) can be used at all common lithographic wavelengths.

Sensitivity of the inspection can be fully adjusted to match photomask specifications for CD control, lineend shortening, OPC features, and for small and large defective areas. An additional adaptive sensitivity option can be utilized to automatically adjust sensitivity as a function of MEEF.

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EDITORIAL

EUV Challenge for “New Economy”

Artur Balasinski, Cypress Semiconductor Corp.

One of my favorite industry experts, Ken Rygler, made once a comment about the EUV: “it has always been fraught with a daunting list of challenges, any one of which can keep a number of engineers, scientists, academics, and students busy for years. An endless flow of papers is assured; commercial success clearly is not.” Where are we on this today, trying to build a “new, better economy” despite old predicaments?

There are several aspects to this point of view. One aspect is that a significant portion of the industry is already committed, for better or worse, to EUV. But a steady stream of publications absent volume production on the horizon seems to align well with Ken’s point. Can one reasonably expect the market to be able to absorb the cost the EUV or is this going to be a white elephant? My favorite Polish poet, Nobel laureate Czeslaw Milosz, wrote: “Learn how to forecast the fire with exactitude. Then burn down the house and your forecast came true.” So is EUV going to become one of these self-fulfilling but deadly prophecies?

Another aspect is that the number of companies which can afford top of the line technologies is inversely proportional to the cost of these technologies. By the time the imaging tools cost half a billion dollars, there would be less than a handful of companies interested in acquiring them. So would all these powerful minds perfecting their knowledge at conferences engaged in developing just two or three steppers worldwide?

But then there is the history. The 1950’s predictions that mankind would never need more than two or three computers globally, did not materialize either. And with Intel announcing the onset of the 22 nm era, I am finding it hard to believe that it would go under due to their extraordinary technological effort, so there has to be marketing benefit to justify it. Perhaps we are not quite able to see it yet. Historically, when the foundries follow the suit, there is enough market drive to fuel up the progress as well. We are looking anxiously at the product designers and expecting they figure out how to make money out of this conceptual power.

If the above is even partially true, the mask community may be looking forward to some bright times. A huge variety of material, optical, data handling, pattern transfer, and application issues can provide an endless, at least from today’s perspective, stream of new solutions, to be debated, to spawn startups, to consolidate, and finally, phase out into oblivion, just as the existing chrome on glass reticles do. And this should be on top of the success of the fringe applications of reticle technologies such as the ones for the hard drives, but also on top of the transition of the old into the new economy. We just need to hang on for another two-three years and keep our fingers crossed.

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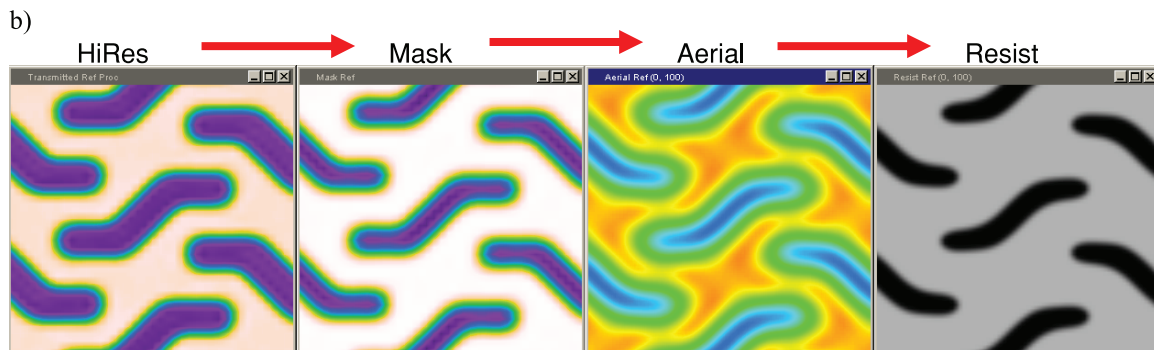


Figure 1. (a) Collection, recovery, and modeling of mask images; (b) actual images from each step.

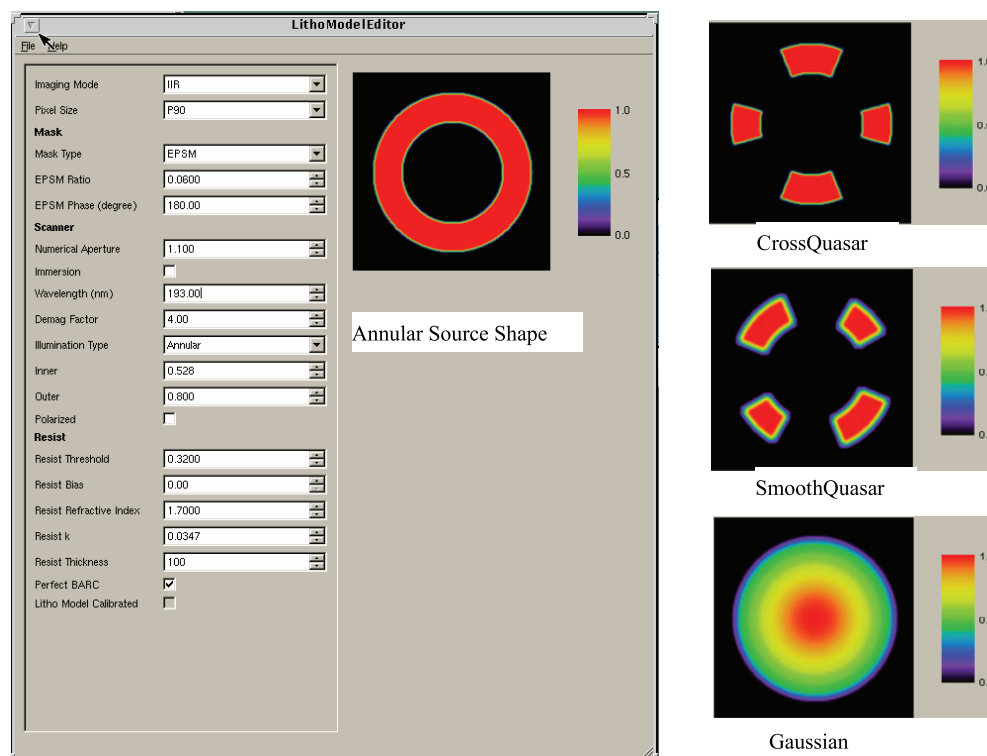


Figure 2. Lithographic inputs to API, source shape options.

Using the Aerial Plane Inspection to compare pattern images has the benefit of filtering out non-printing defects, while detecting very small printing defects. In addition, defects that are not printing at ideal exposure condition, but may be reducing the lithographic process window, can also be detected.

Performing defect detection at the aerial image plane is more tolerant to small Optical Proximity Correction (OPC) sub-resolution assist features (SRAFs) that are difficult to inspect at the reticle image plane.

1. Introduction

Aerial-plane inspection can be an effective solution to the demanding inspection challenges for 45 nm node and below. Based on high resolution Reticle Plane Inspection (RPI) images,

enabled by sophisticated algorithms, API is able to transfer defect detection from the traditional reticle plane to the lithographic plane. This capability adds lithographic significance to each defect in addition to its optical signature.

This paper will explore the application of aerial-plane die-to-die inspections on advanced reticles. It will demonstrate that API improves inspectability of SRAF and complex OPC designs, thus increasing overall usable sensitivity to printing defects. Inspection results on sensitivity and inspectability will be analyzed and evaluated.

1.1 Differences from RPI and WPI

Utilizing API images for defect detection has several potential

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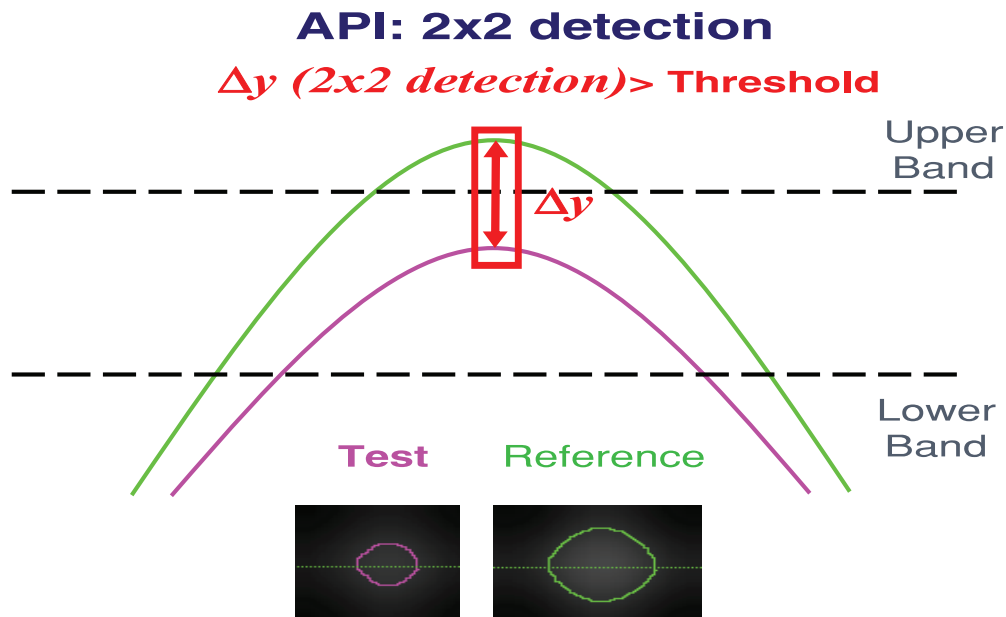


Figure 3. Intensity difference in Aerial plane.

advantages over RPI and Wafer Plane Inspection (WPI). On chrome/MoSi defects are inherently not present in the API images, and thus reduce the number of nuisance detections of real, but non-printing defects. In addition, non-printing sub-resolution assist features (SRAFs) can be automatically de-sensed, as their intensity values will lie outside of the exposure threshold band defined by the user. Note that some sensitivity to SRAF features may be retained through the De-sense band detectors, which is useful for process monitoring in the mask manufacturing process.

API reports defects based on intensity differences between test and reference images at the aerial plane, whereas WPI applies a resist model to the aerial image to enhance discrimination between printable and non-printable defects at the wafer plane. The WPI single threshold model does not allow for any detection of near-printing defects. Those defects that are non-printing at ideal focus and exposure conditions may begin to print at non-optimal conditions. The “banding” of a range of intensities in API can catch defects that are only seen at non-optimal lithographic conditions.

2. Overview

2.1 Collecting Hi-Res images

High resolution transmitted and reflected images are captured simultaneously during scanning of the photomask. Pixel size is selectable between 72, 90, or 125 nm resolution. After capturing the high resolution images in the reticle plane simultaneously, a process called mask pattern recovery (MPR) is invoked, which utilizes a rigorous combination of both the transmitted- and the reflected-light images to recover the actual pattern including any pattern defects on the mask. This recovery of the mask pattern is dependent on the resolution of the imaging system and not on the wavelength of the system. Hence, the use of a sufficiently high-resolution inspection tool at any wavelength is appropriate for this application.

2.2 Conversion to Aerial Plane

Using the recovered mask pattern, an actinic simulation of the imaging process at the wavelength of the scanner is then performed to generate an aerial image of the mask in the resist film. This simulation uses a rigorous formulation based on Hopkins's equation to generate the aerial plane image using either vector or scalar models. The ability to include the full vector/polarization effects is crucial for hyper-NA lithography.

Two of the significant advantages of using a software simulation approach to detect defects at the aerial plane are flexibility and ease-of-use. As shown in Figure 2, there is a great degree of control and flexibility in the formation of the aerial image. The ability to use file inputs for source illumination profiles, enables both arbitrary source illumination profiles that are increasingly important for advanced lithography, and actual measured scanner illumination profiles instead of idealized profiles.

2.3 Creating Difference images and finding defects

API reports defects based on intensity differences between test and reference images at the aerial plane, as shown in Figure 3. Both die are modeled to the Aerial Plane, and a pixel by pixel subtraction performed to create a difference image. A 2x2 area comparator is then applied across all pixels, creating a difference sum value for each pixel. This difference sum is then compared to the threshold value as defined by the sensitivity selector. If the sum is greater than the threshold, a defect is reported. The threshold may change for each pixel as determined by 1) In-band or Out Of Band; 2) Defect Type (Corner, Ctm, Ctm Corner); 3) Adaptive Sense adjusted threshold.

3. Inspection Preparation

3.1 Selecting lithographic conditions

The lithographic parameters must be set correctly in order for the Aerial model to perform accurately. These parameters,

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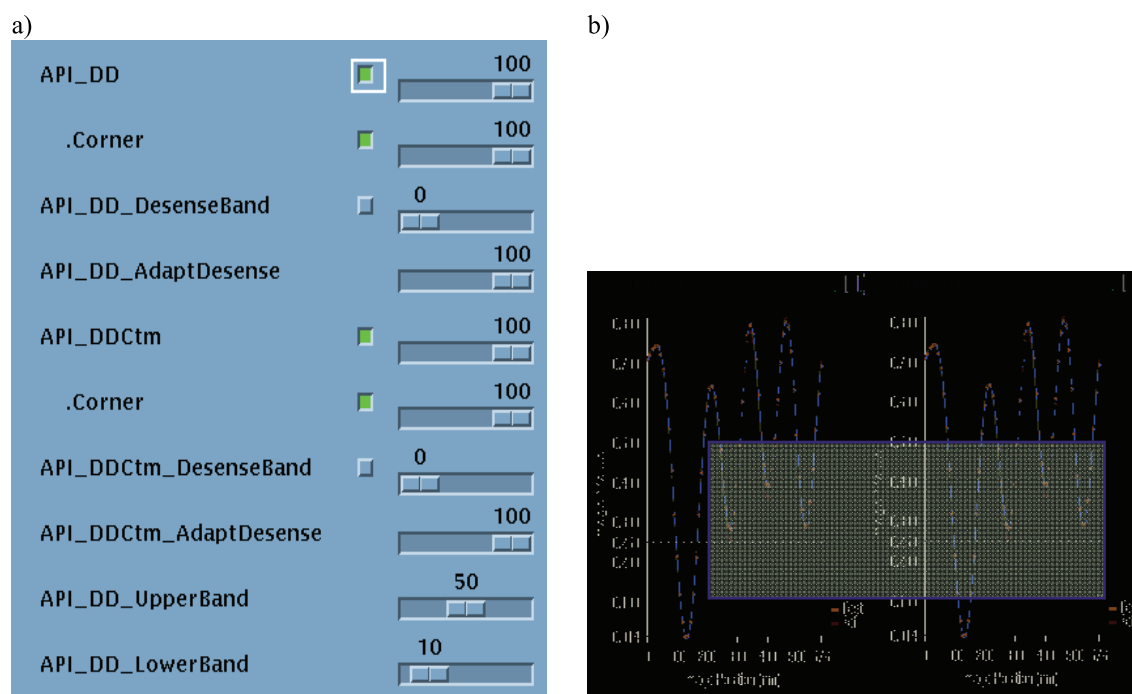


Figure 4. Sensitivity options and typical Upper and lower band selection.

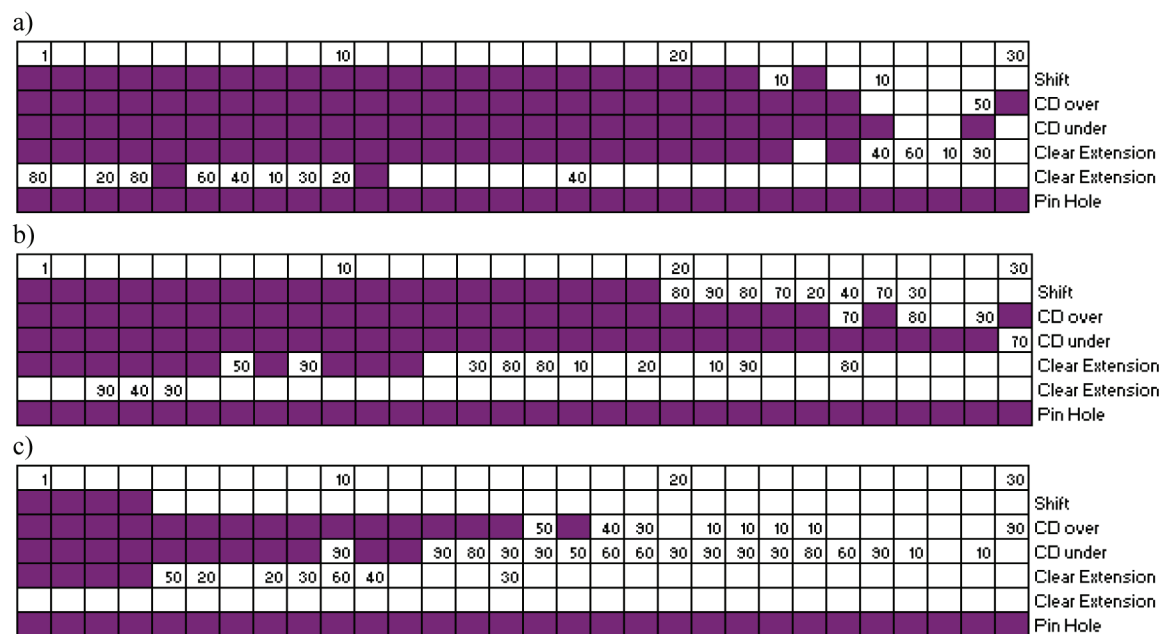


Figure 5. Sensitivity to programmed defect test mask, (a) Reticle Plane Inspection Sensitivity; (b) Aerial Plane Inspection Sensitivity; (c) Wafer Plane Inspection Sensitivity.

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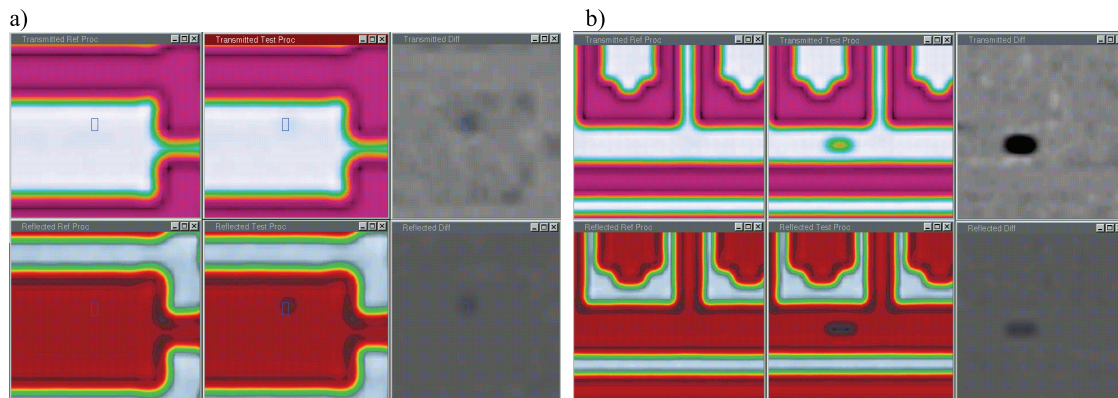


Figure 6. Defects found in Reticle Plane only. a) Small contamination, b) Missing SRAF.

shown in Figure 2 above, include Imaging Mode, Mask, Scanner, and Resist parameters. Lithographic models can be saved for repeated use. Aerial Image Mask Simulation (AIMS) is typically selected for Imaging Mode. As previously discussed, a virtually infinite variation of scanner conditions can be selected, included phase shift and immersion settings. Scanner source shapes can be selected from preset default types, or an arbitrary source shape created from actual measured scanner data. Polarization can also be selected. Resist threshold and parameters are not required, but may be entered to get an accurate model for the resist image in review. An additional feature provided is encryption of the Litho Model file to avoid sharing of company intellectual property.

3.2 Selecting sensitivity

In API, users can select a specified aerial intensity range, (the upper band and the lower band,) in the aerial plane for defect detection. Different sensitivity settings can be applied to in-band region (between upper band and lower band) and out-band regions (above upper band or below the lower band). Given this freedom, users can optimize the recipe to meet different sensitivity requirements while filtering out nuisance defects, thus improving overall usable sensitivity and inspectability. In addition, an Adaptive Desense option is available that can automatically lower the sensitivity of API_DD or API_DDCtm main sliders and sub-sliders in high contrast regions of the mask where the lithographic impact of defects is less likely.

4. Experimental Results

All of the following inspections were performed on a KLA-Tencor® TeraScan 547XR™ advanced reticle inspection tool utilizing the latest RPI, API, and WPI algorithms. Inspections were performed at the KLA-Tencor manufacturing site, and at Samsung Electronics New Research and Development facility.

4.1 Programmed defect test mask

The first experiment performed is on a 3x hp node Line/Space pattern 6% EPSM 193 nm wavelength Immersion photomask. Ten runs were performed to measure sensitivity to the programmed defects. All inspections were performed using the 72 nm pixel at best sensitivity/inspectability settings. Sensitivity

results are shown in Figure 5. Shaded area represent 100% capture rate over ten consecutive inspections. Values indicate percentage capture when less than 100%.

As observed in the sensitivity table, API inspection compared to traditional RPI inspection is less sensitive to clear defects that are less likely to print on the wafer, however the under-sized CD defect type has increased in sensitivity. WPI has even less sensitivity to these smaller defects, showing that the defects in the resist image are less significant.

In addition, small contamination or missing SRAF features which do not affect the printed wafer are not detected by API. Two defect images are shown in Figure 6 that are detected by RPI only. This shows that API can be used to reduce nuisance defect detections and enable a more sensitive inspection to the defects which do print, or are in a band around the exposure level of the resist which could reduce exposure latitude in the wafer process.

4.2 Production mask data

A production plate was partially inspected with RPI, API, and WPI algorithms to determine the capability of each mode. This plate is a 4x hp node CoG plate used in 193 nm lithography. Results of each inspection are shown in Figure 7. In order to quantify the lithographic significance of real defects, sub classifications were made for On Pattern, On Opaque, and On Edge, and on SRAF

As predicted, SRAF and On Opaque defects are not reported on the Aerial and Wafer plane inspections. Because of its higher sensitivity, API is able to capture more real pattern defects than RPI inspection, including defects due to edge placement. These last defects do not propagate into the resist image, but could impact wafer critical dimensions when lithography conditions are not optimal.

Furthermore, in addition to API's inspectability advantage on SRAF features, it also has the ability to detect the impact of SRAF defects on the main feature. In Figure 8, a CD defect was captured by API D:D where the detection was triggered not by the broken SRAF, but by its impact on the main feature. The aerial intensity plot shows the intensity difference between Test and Reference images on the SRAF is outside of the upper band. Yet its impact on the main feature is what triggered the detection as illustrated by the defective pixels highlighted in red.

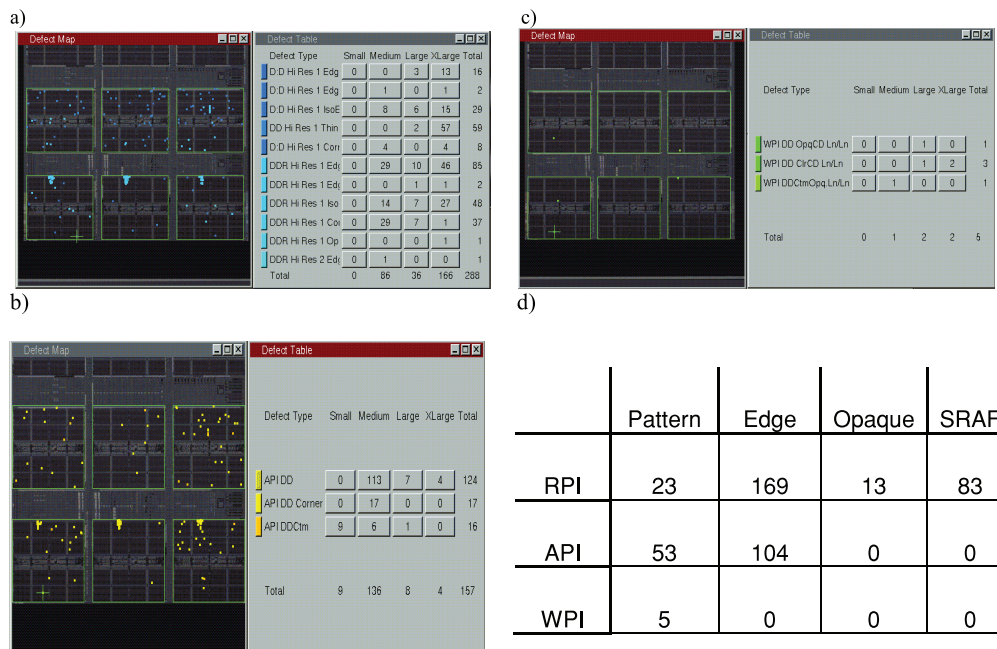


Figure 7. Inspection map and classification of defects on sample production mask a) RPI results; b) API results; c) WPI results; d) summary table.

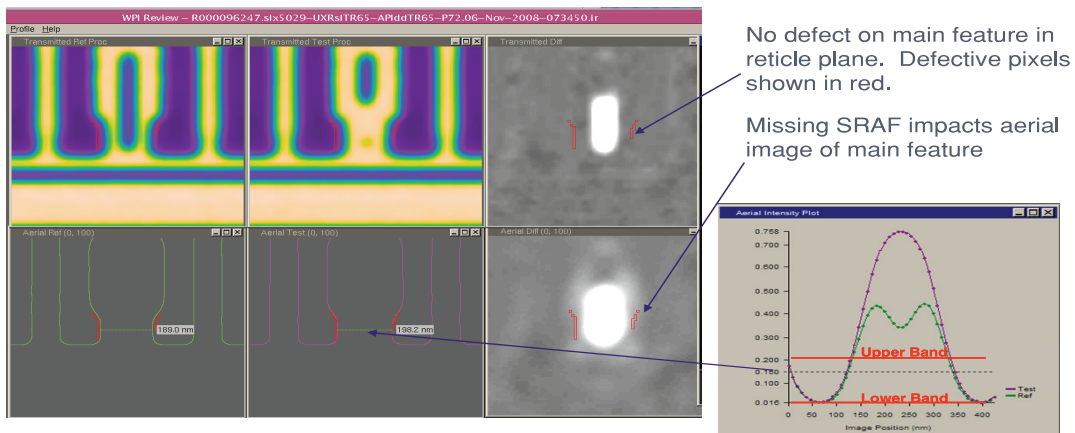


Figure 8. Defect on the main feature caught by API as a result of a broken SRAF.

5. Conclusions

Aerial Plane Inspection methodology can effectively filter out real mask defects that do not impact the area of interest in the Aerial Intensity plane. Defects such as contamination on chrome or MoSi will never be detected by the API inspection. Additionally, missing or mis-formed SRAF features will not be detected in the Aerial plane, but in the instance that the main feature is distorted due to the SRAF change defects will be detected. Utilizing the Out-of-Band detector, process induced defects such as missing SRAFs or small contamination on clear areas will be detected, allowing the mask manufacturer to continuously monitor their process, while still ensuring no printing defects are contained on the mask.

6. Acknowledgments

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Industry Briefs

■ Ultratech: Ready for FinFETs at 16 nm

As the equipment industry hopes for a better economy, Ultratech's works out the overlay issues related not just to the lithography, but to the melt laser spike anneal (LSA). Customers are evaluating melt technology at 22nm, 16nm, and even sub-16nm nodes, before one manufactures the actual production melt system. Ultratech expects a transition from sub-melt LSA to melt LSA at around 22nm with more emphasis at 16nm where the issue of leakage has worsened. Mobile applications (smart phones and netbooks) require both high performance and low leakage that are proving to be serious challenges when have to be met simultaneously.

LSA can go to higher process temperatures that increase junction activation—forming more abrupt junctions—so leakage is lowered. The higher process temperatures are possible because only a very thin surface layer of the wafer (where the transistors are formed) is heated. Furthermore, dwell times (at elevated temperature) are very short; annealing times can be on the order of milliseconds, microseconds, or, at the melt condition, nanoseconds. And while high-k/metal gate itself reduces leakage by a factor of ~10x, LSA provides an additional 3x-5x reduction.

Another major concern at advanced nodes is lithography overlay error. Because LSA is able to keep stress in the wafer low—only a small portion of the wafer at any given time is heated and the dwell time is short—it is able to meet the ever more stringent lithography overlay requirement. And when the industry is ready to move to FinFET structures, LSA is extendible. Millisecond annealing tools will be challenged to deal with FinFETs.

■ Molecular Imprints Enables Low-Cost Patterned Media: New Template Replication

Molecular Imprints, Inc., a nanopatterning leader, introduced the Perfecta(TM) TR1100 template replication system for patterned media. Leveraging the company's Jet and Flash(TM) Imprint Lithography (J-FIL(TM)), the Perfecta TR1100 enables the mass-replication of master imprint templates with extremely high fidelity at a cost that is orders of magnitude lower than that of fabricating the original master template. Combined with Molecular Imprints' family of nanopatterning systems, the Perfecta template replication platform will provide a critical component in the manufacturing infrastructure to produce the next generation high-density hard disk drives (HDDs). Molecular Imprints has already sold two Perfecta TR1100 systems, including one that has been formally accepted and installed by merchant mask and HDD disk manufacturer, Hoya Corporation, which will facilitate the commercial availability of imprint templates for advanced patterned media development and pilot production.

The transition to patterned media represents a fundamental shift in the hard disk drive industry, introducing new processes and requiring new equipment in the disk media production. With changes in the fabs, the last thing that HDD manufacturers should have to worry about is the complexity and costs associated with manufacturing templates. The HDD industry is currently adopting J-FIL as it transitions to advanced patterned media. To maintain the historical 40-percent annual growth in HDD areal density to one terabit per square inch and beyond will require patterned media with critical dimensions under 20nm, at less than one tenth the cost of current semiconductor patterning. However, producing master templates using e-beam in the volume needed to support patterned media production is cost-prohibitive. A new approach is required to deliver the resolution of e-beam technologies at a much lower cost—the very characteristics of Molecular Imprints' J-FIL technology. Once a master template is created using traditional e-beam technologies, the Perfecta template systems can replicate it thousands of times with extremely high pattern fidelity. Each of the subsequent template replicas or "daughter" templates that are produced can then be employed to produce thousands of disks at low costs.

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Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

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2010



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*Late abstracts will be considered
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SPIE Photomask Technology

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